Sustainability in Computing

Energy Efficient Placements of Kubernetes Workloads

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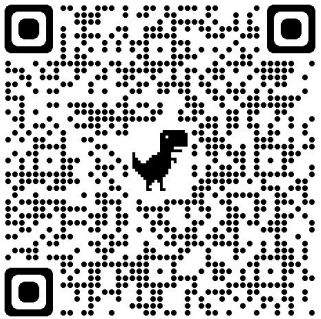
Red Hat

Who We Are

CLOUD NATIVE
COMPUTING FOUNDATION

- Community based initiatives on environmental sustainability
- Proposal: **CNCF TAG Environmental Sustainability**
- Carbon Aware Scaling with KEDA
    - a community based initiative; investigates how to use electricity carbon intensity to make workload scaling decisions.
- CLEVER:
    - Container Level Energy-efficient VPA Recommender for Kubernetes



Agenda

- Background
- Introduce our Sustainability stack
  - Kepler
  - Model Server
- Demo

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Background

According to Gartner, “In 2021, an ACM technology brief estimated that the information and communication technology (ICT) sector contributed between 1.8% and 3.9% of global carbon emissions.

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Background

- How to measure energy consumption indirectly?
- How to measure energy consumption of workloads?
- How to attribute power on share resources to processes, containers or Pods?

Introducing the Cloud Native Sustainability Stack

1. Kepler
2. Kepler Model Server

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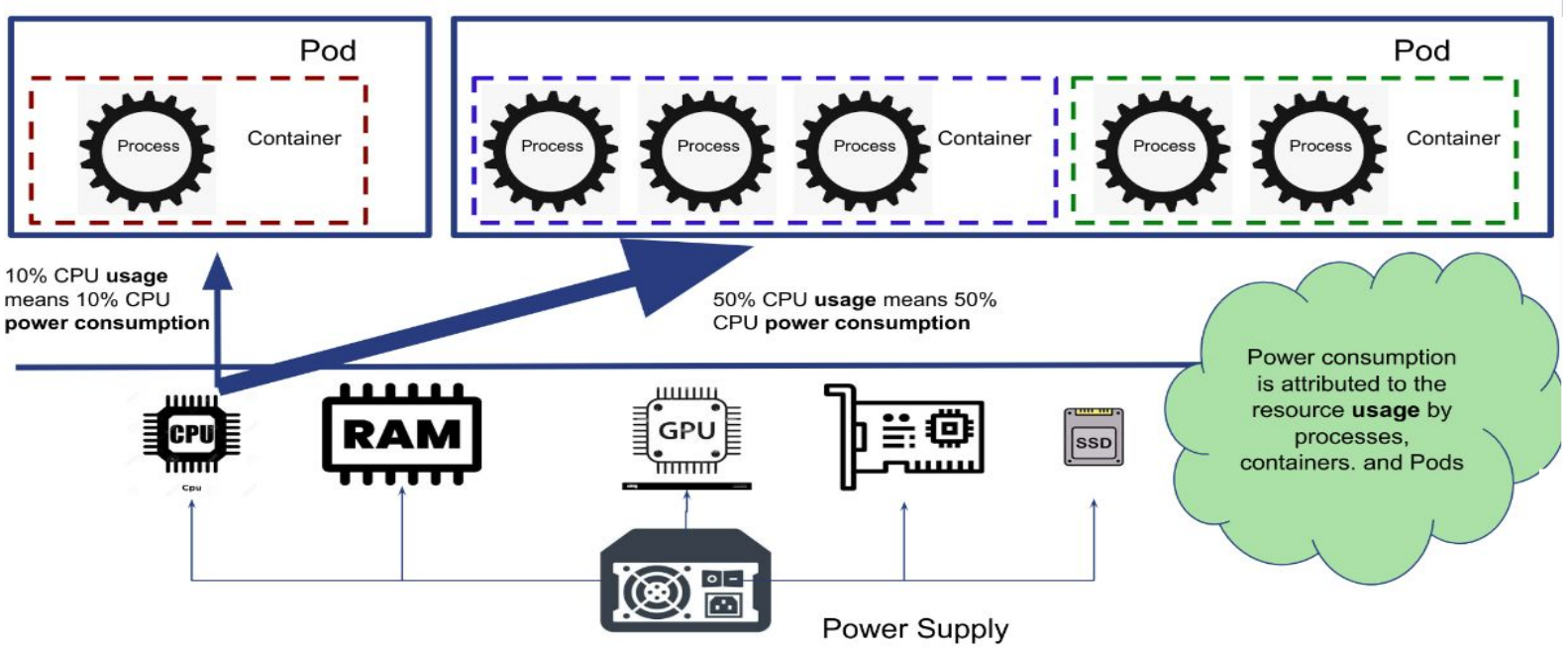
Energy Consumption Attribution Methodology



Reference: https://lca.ece.utexas.edu/pubs/bircher-TC2012.pdf

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Kepler

Kubernetes based Efficient Power Level Exporter

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Kepler: Kubernetes based Efficient Power Level Exporter

Uses software counters to measure power consumption by hardware resources and exports as Prometheus metrics

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Reporting

- Per Pod level energy consumption reporting, including **CPU/GPU, RAM**
- Support **bare metal** as well as **VM**
- Support **Prometheus**

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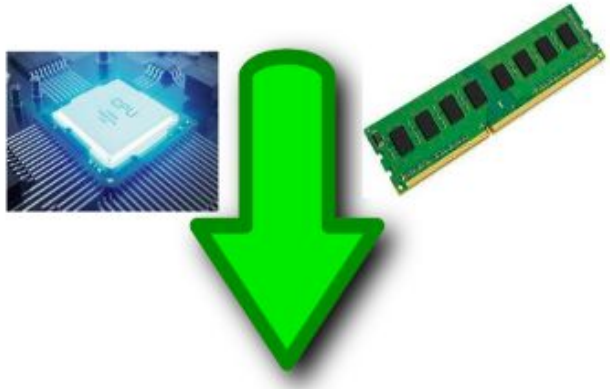

Reduction

- Reduced computational resource used by the probe
- Using **eBPF**

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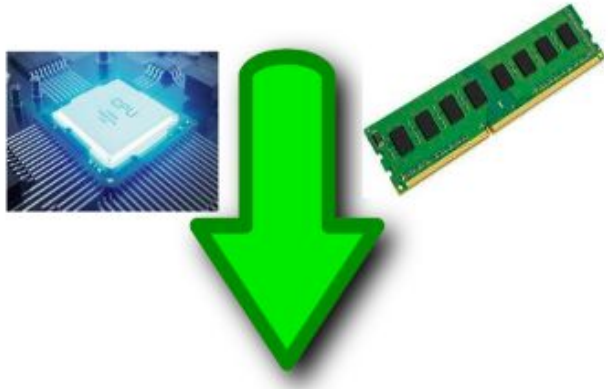

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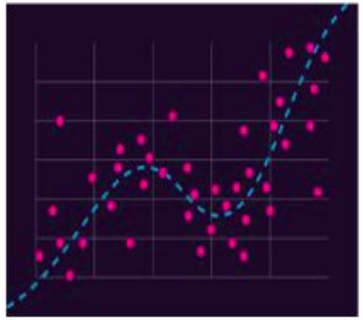

Regression

- Support **ML** models to estimate energy consumption
- Science based approach

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Kepler Model Server

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About Kepler Model Server

- Default: Kepler uses supported power meter tools to measure node level energy metrics (CPU core, DRAM, Pod Energy)
- Problem: No supported power meter for Kepler
- Model Server Goal: Provide Trained Models for Kepler that use Software Counters/Performance metrics to predict missing energy metrics
- Current Tech Stack: Tensorflow Keras, Scikit, Flask, Prometheus

Kepler Model Server's Models

- CPU Core Energy Consumption Model: Linear Regression
  - Label: **CPU Core Energy Consumption**
  - Features: **cpu_architecture, curr_cpu_cycles, curr_cpu_instructions, curr_cpu_time**
- Online Learning

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Kepler Model Server's Models Cont

- Dram Energy Consumption Model: Linear Regression
  - Label: **DRAM Energy Consumption**
  - Features: **cpu_architecture, curr_cache_misses, memory_working_set**
- Online Learning

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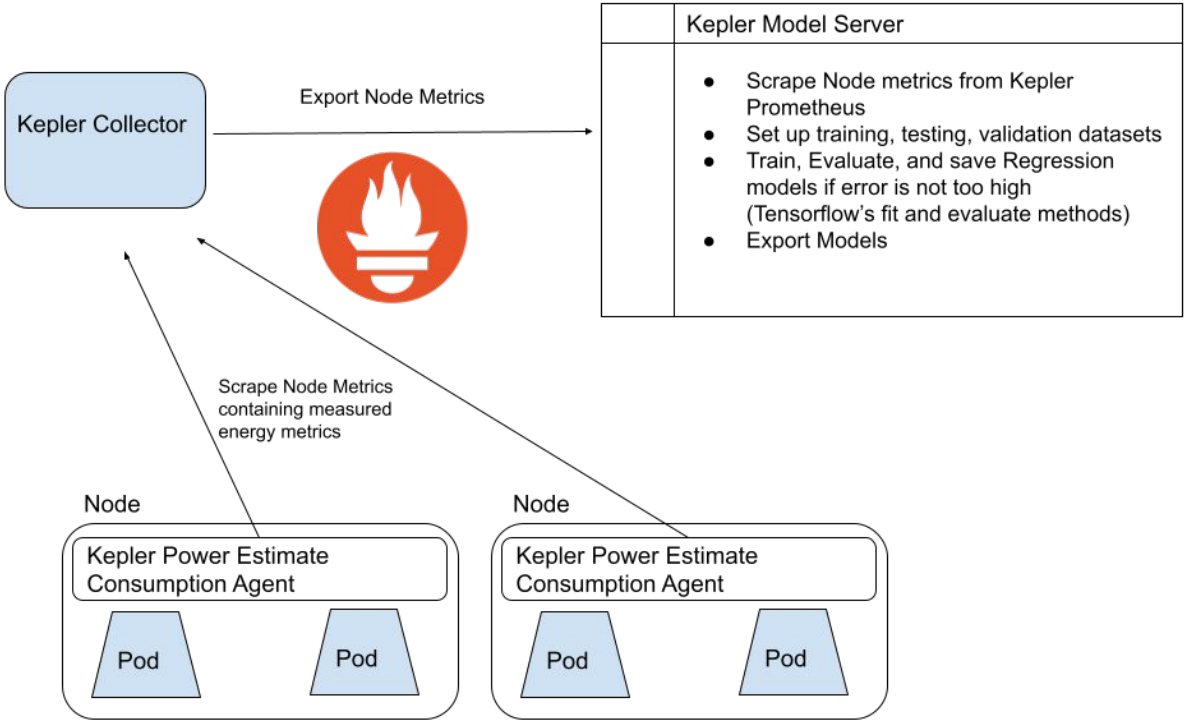
Model Server and Kepler

Training Phase



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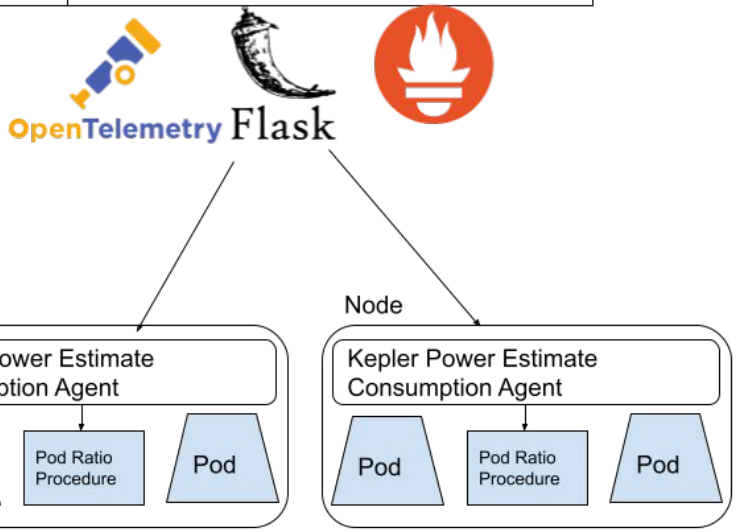
Model Server and Kepler

Exporting Phase

	Kepler Model Server
	• Scrape Node metrics from Kepler Prometheus • Set up training, testing, validation datasets • Train, Evaluate, and save Regression models if error is not too high (Tensorflow's fit and evaluate methods) • Export Models



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Carbon Intensity Aware Scheduling

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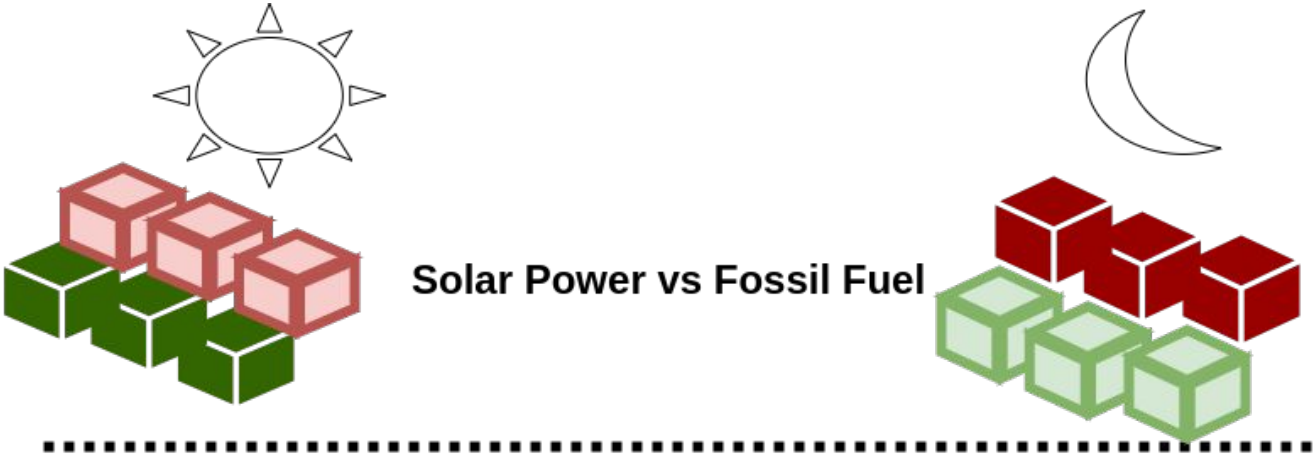
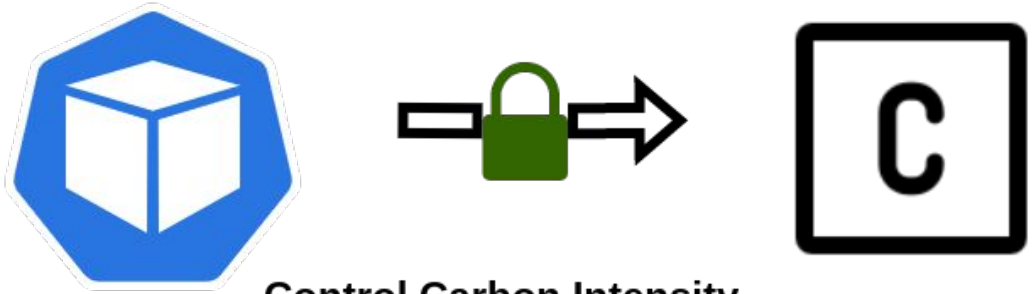
Use Cases





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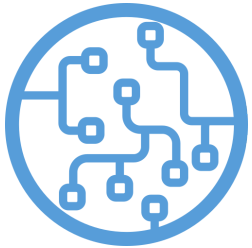
Use Case Premise

- Multi-node cluster
- Nodes in different zones
- Long running batch/ML workloads

Demo Set Up

- OpenShift Cluster
- Monitoring: Prometheus
- Taints/Tolerations/NodeSelectors
- Carbon Intensity Forecaster



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Carbon Intensity Forecaster

- Exporter scrapes from Public Energy APIs (ex. Electricity Map) and exports as Prometheus metrics
- Scrapes prometheus metrics from the exporter to update models for each node
- Carbon Intensity Forecaster and Exporter are extendable interfaces

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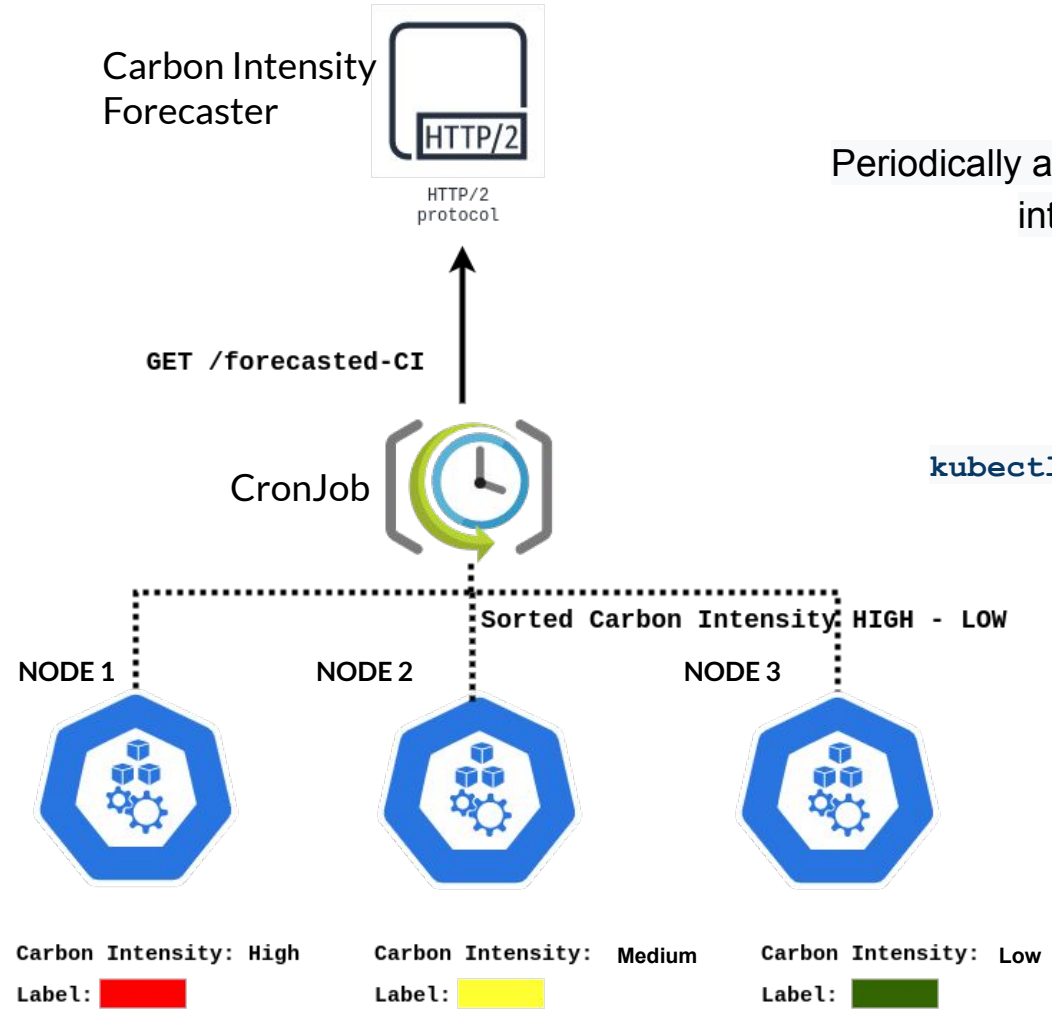

Node labels

Periodically assign node labels according to forecasted carbon intensity of the zone the node is present

```
kubectl label nodes ip-10-0-169-34.ec2.internal
carbon_intensity=green
```

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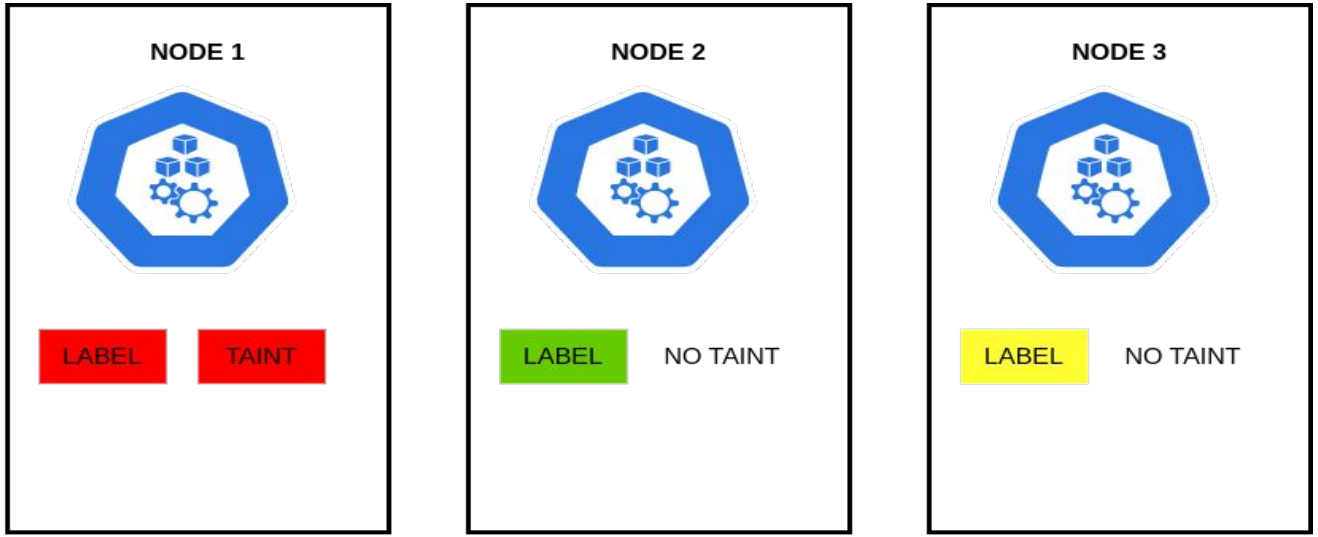

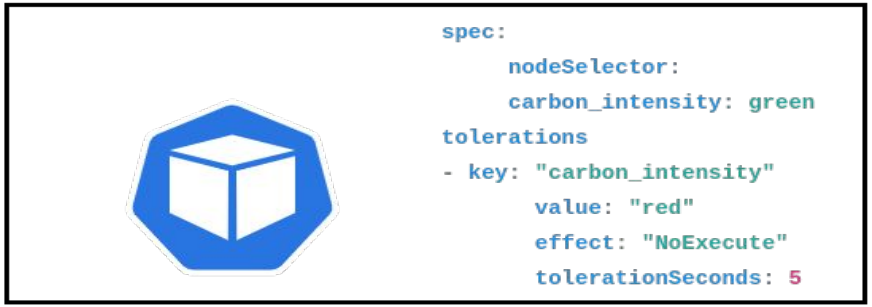

```
spec:
     nodeSelector:
     carbon_intensity: green
tolerations
- key: "carbon_intensity"
       value: "red"
       effect: "NoExecute"
       tolerationSeconds: 5
```

tolerationSeconds

means that if this pod is running and a matching taint is added to the node, then the pod will stay bound to the node for 5 seconds, and then be evicted.

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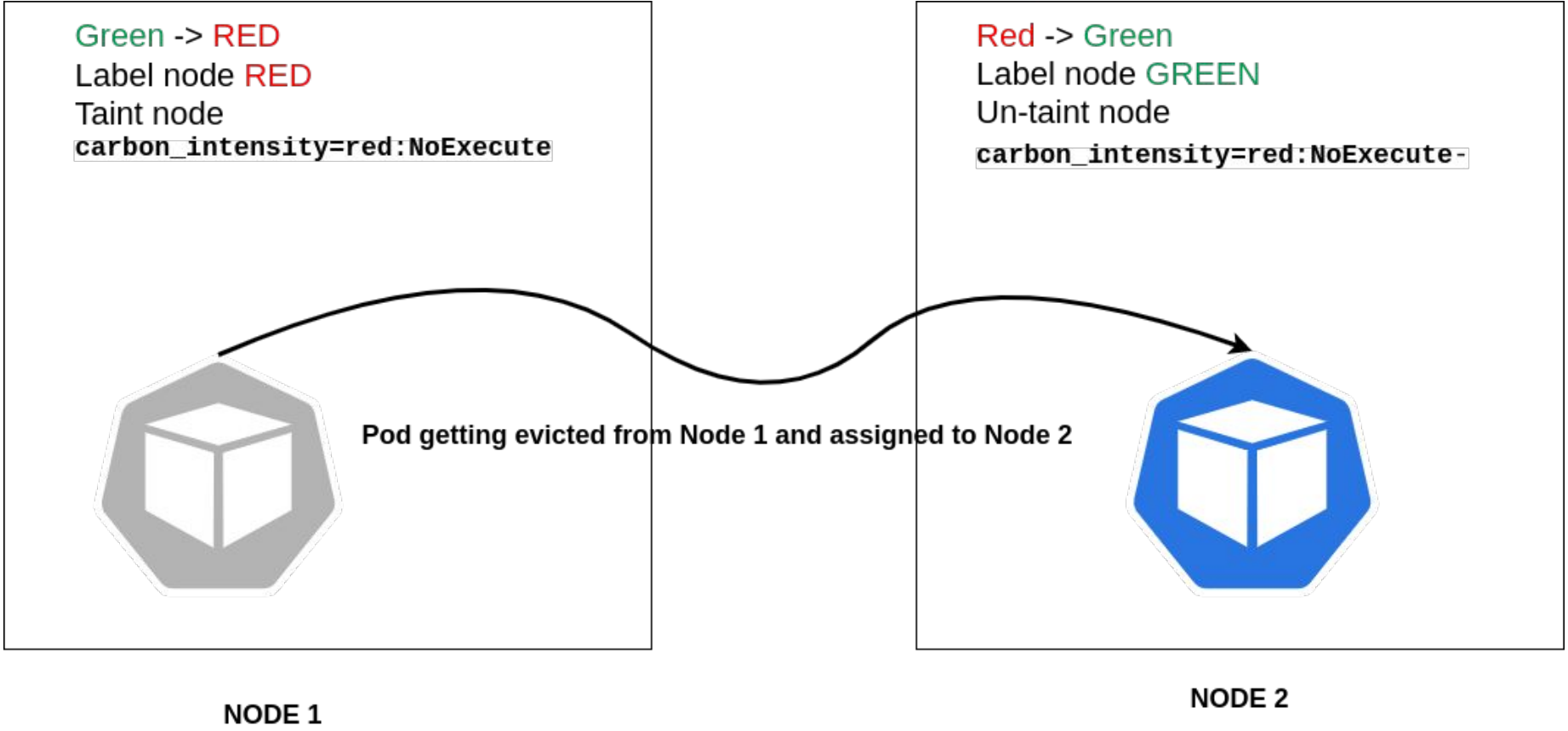

Tainting nodes ensure pods are evicted by the nodes if pods have no tolerations for the taint.

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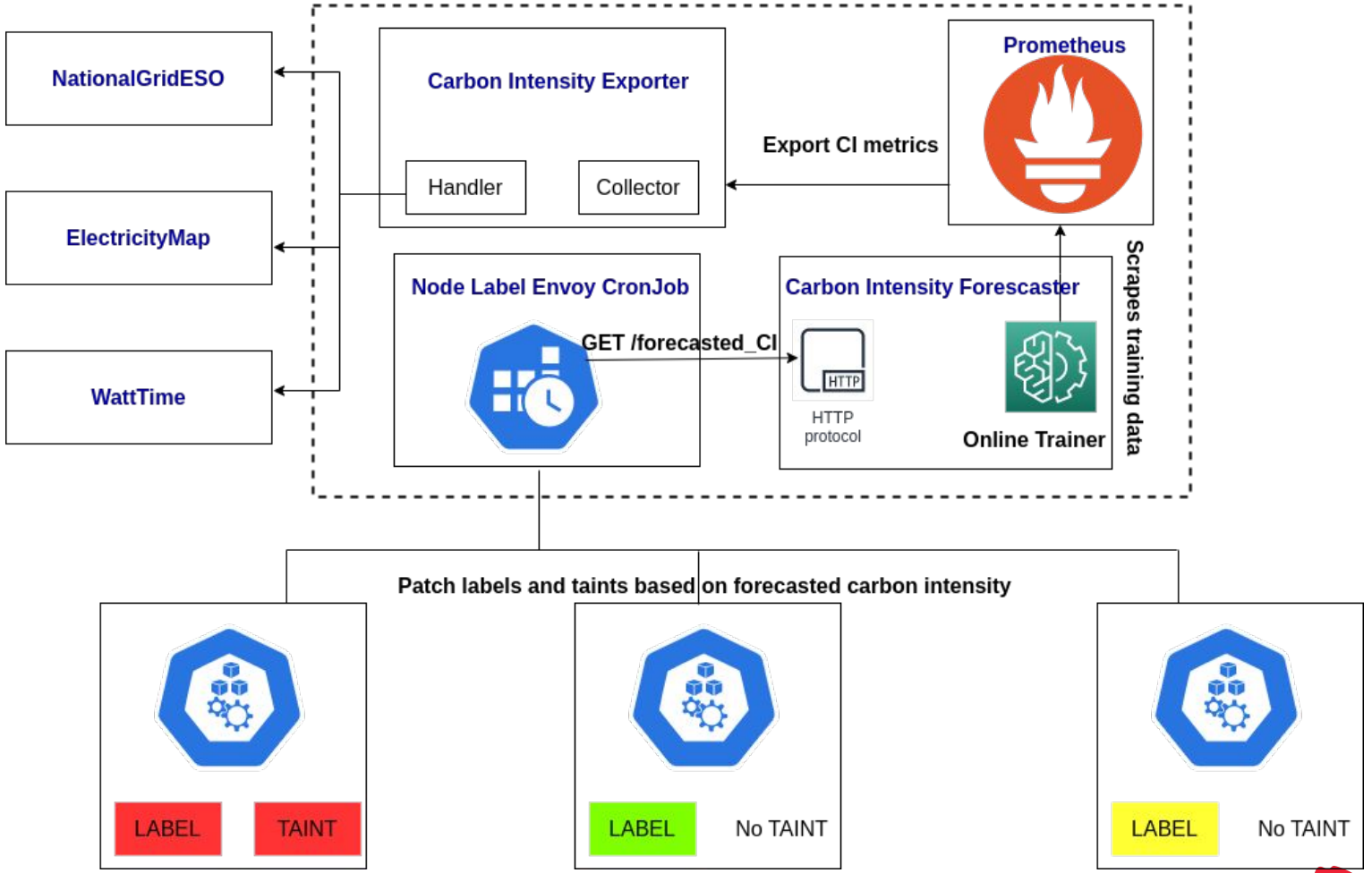
NationalGridESO
ElectricityMap
WattTime
Carbon Intensity Exporter
Handler
Collector
Export CI metrics
Prometheus
Scrapes training data
Node Label Envoy CronJob
GET /forecasted_CI
Carbon Intensity Forecaster
HTTP
HTTP protocol
Online Trainer
Patch labels and taints based on forecasted carbon intensity
LABEL
TAINT
LABEL
No TAINT
LABEL
No TAINT

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Demo

Demo - Kepler Operator

Overview

https://github.com/sustainable-computing-io/kepler-operator

Release

v1alpha1

Features:

- Pre-requisite Cgroup v2
- Follows Kepler v0.4
- Deploy's Kepler on Kubernetes and OpenShift
  - Pre-configuration for OpenShift (MachineConfig and SCC)
- Uses offline model
  - Uses local linear regression estimator in Kepler main container with offline trained model weights.

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Demo - Lessons Learnt

- Finding Zone Carbon Intensity Data
  - Some time points are missing

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Demo - Lessons Learnt

- Finding Zone Carbon Intensity Data
- Need to support multiple query types
  - It is easy to query threshold friendly metric on Prometheus (e.g. what is the current or average carbon intensity in zone XYZ?), but hard on others (no threshold or more complicated logic)
    - Which zone has the lowest carbon intensity?
    - Is the current carbon intensity low, e.g. within the past 24 hours?

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    - Which zone has the lowest carbon intensity?
    - Is the current carbon intensity low, e.g. within the past 24 hours?
- Need to support multiple electricity carbon emission providers
  - Improve and integrate with Green Software Foundation carbon-aware SDK

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Road Ahead

- Apply to multi-cluster
  - Explore approach with kcp
- Integrate carbon-intensity awareness in kubernetes-sigs/scheduler-plugins
  - Use Trimaran TargetLoadPacking profile and integrate carbon-intensity awareness in the scheduler
  - Tune Trimaran for energy efficiency.

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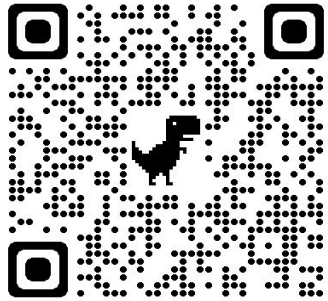
References

- How to use performance counters to estimate power consumption by cpu, memory, etc https://lca.ece.utexas.edu/pubs/bircher-TC2012.pdf
- Kepler : https://github.com/sustainable-computing-io/kepler
- The Model Server: https://github.com/sustainable-computing-io/kepler-model-server



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Thank You